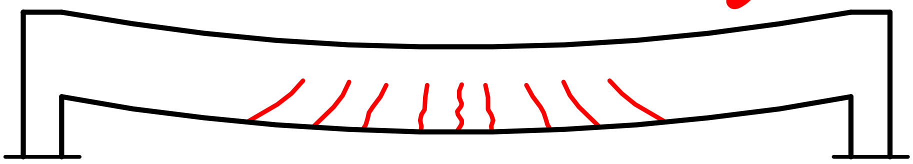
Serviceability.



Deflection & Cracks Limit States.

نسألكم الدعاء

IF you download the Free ***APP.*** **RC Structures** YASSER EL LEATHY *on your smart phone or tablet, you will be able to play illustrative movies For any paragraph that has a QR code icon*

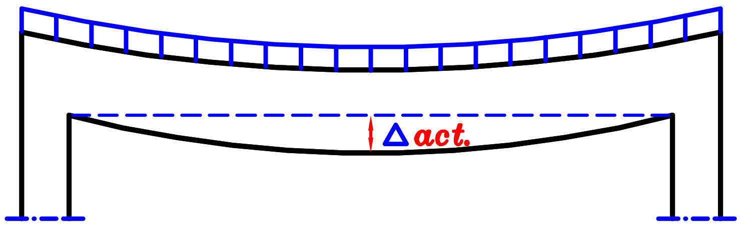
اذا حملت تطبيق **RC Structures** YASSER EL LEATHY على تليفونك المحمول او اللوح السطحى ستستطيع أن تشغل أفلام شرح للمقاطع التى تحتوى على رمز

(*Serviceability*) *Check Deflection & Cracks Control Table of Contents.*

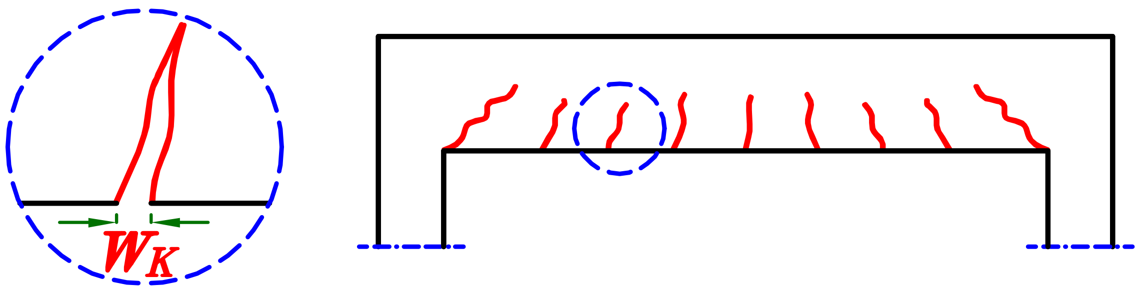
Introuction.

Serviceability تعرف على انها العوامل التى من الممكن ان تضر بالمنشأ و لم يؤخذ تأثيرها فى معادلات التصميم على الاحمال . مثل :

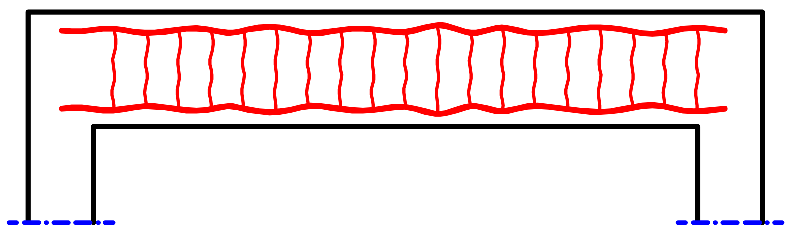
1- Deflection. الترخيم



2- Crack width. الزياده فى عرض الشروخ

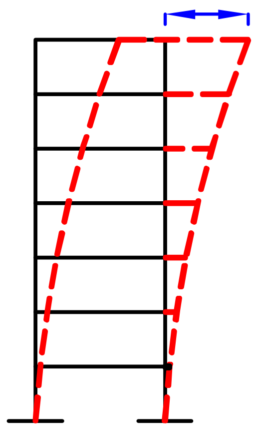


3- Extent of corrosion. زياده معدلات صدأ الحديد



4- Vibrations. زياده اهتزاز المنشأ مثل الكبارى و المصانع

5- Drift. زياده الحركه الافقيه للمبانى العاليه المعرضه للرياح أو الزلازل .



لكى نستطيع حساب قيمه الترخيم *Deflection* أو عرض الشرخ W_K لكمره

سنحتاج لحساب I_{nv} & I_g لقطاع الكمره

I_g = **Gross moment of Inertia.** For **UnCracked Section.**

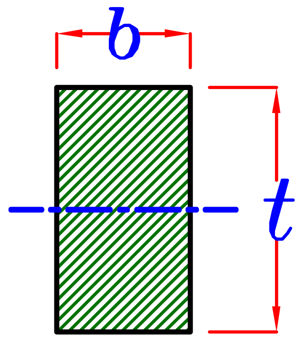
I_{nv} = **moment of Inertia.** For **Cracked Section.**

I_g = **Gross moment of Inertia.** For **UnCracked Section.**

ممكن للتسهيل اهمال وجود الحديد .

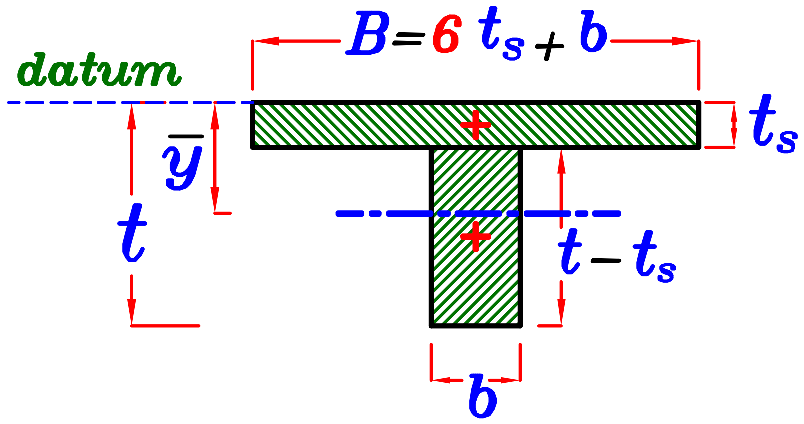
R-Sec.

$$\boxed{I_g = \frac{b * t^3}{12}}$$



T-Sec.

نعتبر ان الجزء المقاوم من البلاطه يساوى $B = 6\ t_s + b$



$$A = B * t_s + b\ (t - t_s)$$

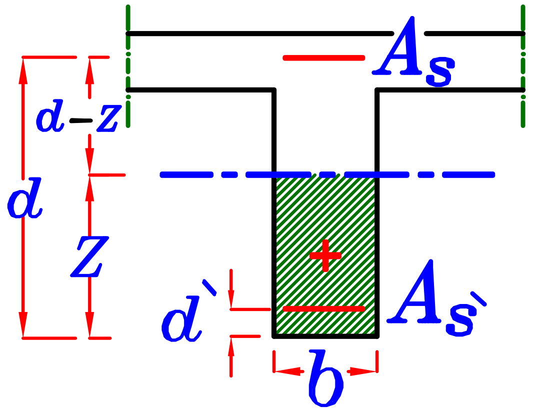
$$\bar{y} = \frac{B * t_s\ \left(\frac{t_s}{2}\right) + b\ (t - t_s)\left[\left(\frac{t - t_s}{2}\right) + t_s\right]}{A}$$

$$I_g = \frac{b\ (t - t_s)^3}{12} + b\ (t - t_s)\left[\left(\frac{t - t_s}{2}\right) + t_s - \bar{y}\right]^2 + \frac{B\ t_s^3}{12} + B\ t_s \left(\bar{y} - \frac{t_s}{2}\right)^2$$

I_{nv} = moment of Inertia. For Cracked Section.

المفروض فى ال **deflection** قيمه ال $\boxed{n=10}$ و ممكن للتسهيل نأخذها ب $\boxed{n=15}$

For R–Sec.

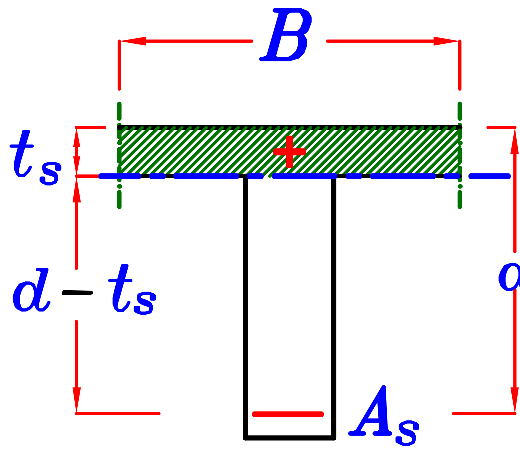


$$S_{nv.\,above\,(N.A.)} = S_{nv.\,under\,(N.A.)}$$

$$\frac{b\,Z^2}{2} + (n-1)\,A_{s`}\,(Z-d`) = n\,A_s\,(d-Z) \longrightarrow \text{Get } Z$$

$$I_{nv} = \frac{b\,Z^3}{3} + (n-1)\,A_{s`}\,(Z-d`)^2 + n\,A_s\,(d-Z)^2$$

For T–Sec.



لكى نعرف هل ال **N.A.** اعلى ام اسفل البلاطه

نفرض ان ال **N.A.** عند البلاطه تماما $Z = t_s$

ثم نحسب قيمه **Snv.** اعلى و اسفل البلاطه و نقارن بينهم

$$S_{nv.}(above) = B * t_s * \frac{t_s}{2}$$

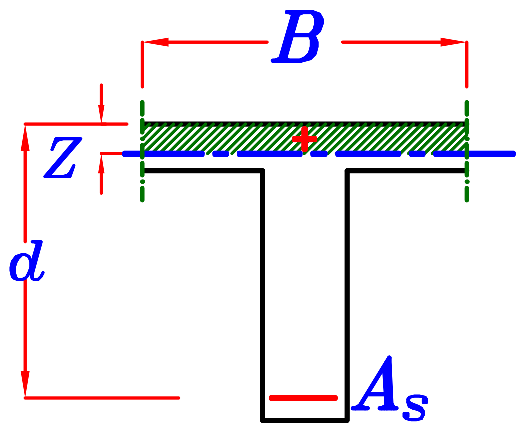
$$S_{nv.}(under) = n\,A_s\,(d-t_s)$$

1 IF $S_{nv.}(under) < S_{nv.}(above) \longrightarrow \boxed{Z < t_s}$

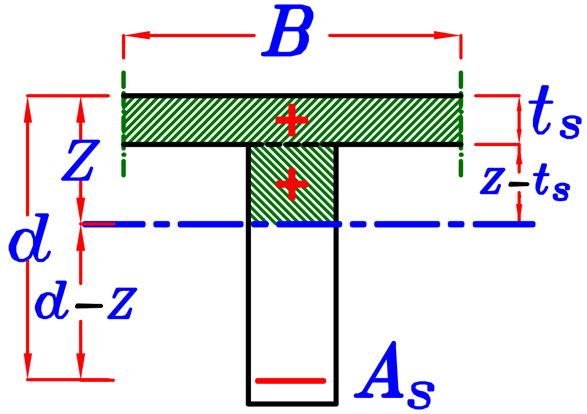
$$S_{nv.\,above\,(N.A.)} = S_{nv.\,under\,(N.A.)}$$

$$\frac{B\,Z^2}{2} = n\,A_s\,(d-Z) \longrightarrow \text{Get } Z$$

$$I_{nv} = \frac{B\,Z^3}{3} + n\,A_s\,(d-Z)^2$$



② IF $S_{nv.}(under) > S_{nv.}(above) \longrightarrow \boxed{Z > t_s}$



$$S_{nv.\,above\,(N.A.)} = S_{nv.\,under\,(N.A.)}$$

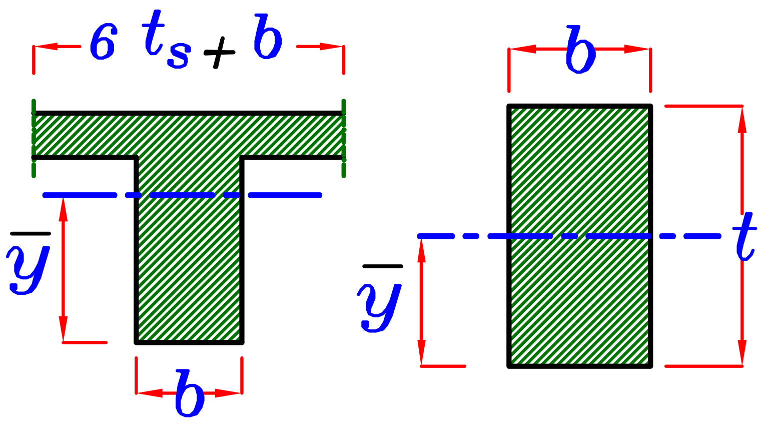
$$B\,t_s\left(Z-\frac{t_s}{2}\right)+b\,(Z-t_s)\,\frac{(Z-t_s)}{2} = n\,A_s\,(d-Z) \text{ ---- Get } Z$$

$$I_{nv} = \frac{B\,t_s^3}{12} + B\,t_s\left(Z-\frac{t_s}{2}\right)^2 + b\,\frac{(Z-t_s)^3}{3} + n\,A_s\,(d-Z)^2$$

---

* M_{cr} = Cracking Moment.

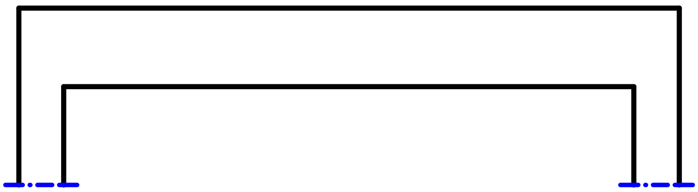
$$\boxed{M_{cr} = F_{ctr} * \frac{I_g}{\bar{y}_{ten}}}$$



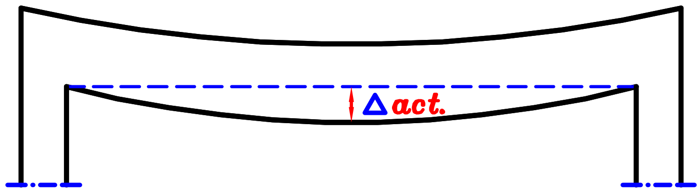
where

$$\boxed{F_{ctr} = 0.6\,\sqrt{F_{cu}}}$$ $N\backslash mm^2$ ممكن إهمال وجود الحديد

Check Deflection.



قبل التحميل



بعد التحميل

Effects of Deflection.

عيوب حدوث ترخيم كبير للكمرات

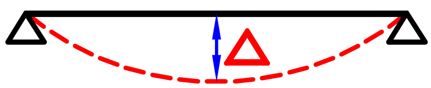
1– Excessive Vibrations and bad Feelings.

حدوث اهتزازات أكبر و احساس سيئ لشكل الترخيم .

2– Damage of partitions , doors , windows and Finishing.

حدوث تأثير سيئ على الحوائط و الابواب و الشبابيك و الارضيات .

Factors affecting deflection value.



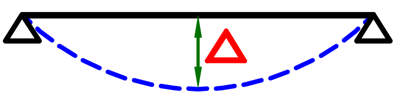
1 – Loads. $\Delta \propto$ Loads

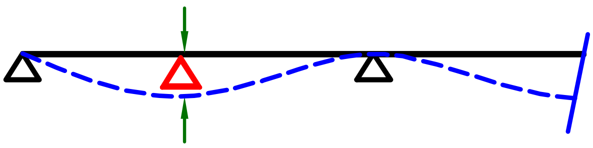
2 – Spans. $\Delta \propto$ span

3 – Modulus of Elasticity. (E) $\Delta \propto \frac{1}{E}$

4 – Moment of Inertia. (I) $\Delta \propto \frac{1}{I}$

5 – Continuity of beams. $\Delta \propto \frac{1}{\text{Continuity}}$





نعمل Check Deflection لكى نعرف اذا كان ال Deflection فى حدود المسموح به أم لا .

فنحسب قيمه ال Deflection الفعلى $\triangle_{act}$ الذى تعتمد قيمته على :

الاحمال الواقعه على الكمره Working Load و طول الكمره L

و أبعاد قطاع الكمره effective Inertia I_e و ماده القطاع E_c

ثم نحسب قيمه ال Deflection المسموح به $\triangle_{all}$ من الجداول او من الكود .

و نقارن كلا من $\triangle_{act}$ و $\triangle_{all}$

$$IF \ \triangle_{act} \leqslant \triangle_{all} \longrightarrow \text{Safe Deflection.}$$

$$IF \ \triangle_{act} > \triangle_{all} \longrightarrow \text{Unsafe Deflection.}$$

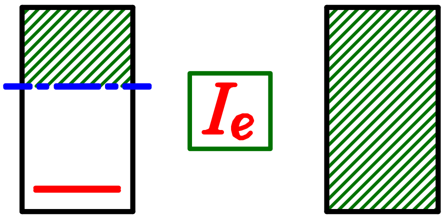
$$\boxed{\triangle_{act} = \frac{\checkmark}{E_c * I_e}}$$

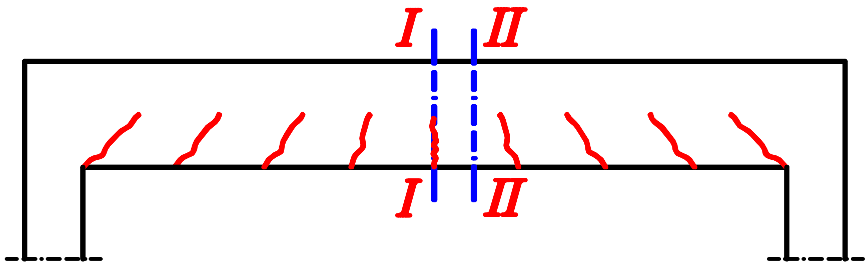
لكى نحسب قيمه $\triangle_{act}$ يجب أولا أن نحسب قيمه E_c & I_e

E_c = Modulus of Elasticity For Concrete

$$\boxed{E_c = 4400\sqrt{F_{cu}}} \quad N\backslash mm^2$$

I_e= Effective Moment of Inertia For the cracked Sec.





Sec. I
Cracked sec.
I_{nv}

Sec. II
Non Cracked sec.
I_g

فى الكمرات المشرخه توجد قطاعات مشرخه و قطاعات اخرى غير مشرخه

فى القطاعات المشرخه تكون I_{nv} و فى القطاعات الغير مشرخه تكون I_g

اذا للتعبير عن قطاعات الكمره كلها نحسب I_e و تكون قيمتها بين كل من I_g & I_{nv}

و تعتمد قيمه I_e على كميه الشروخ فى الكمره أى تعتمد على قيمه كل من M_{cr} & $M_{act.}$

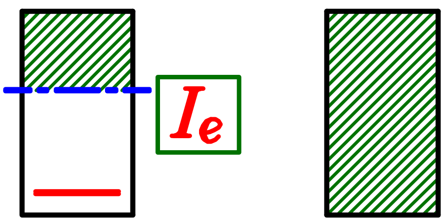
حيث M_{cr} هو العزم الذى تبدأ عنده الكمره فى التشرخ .

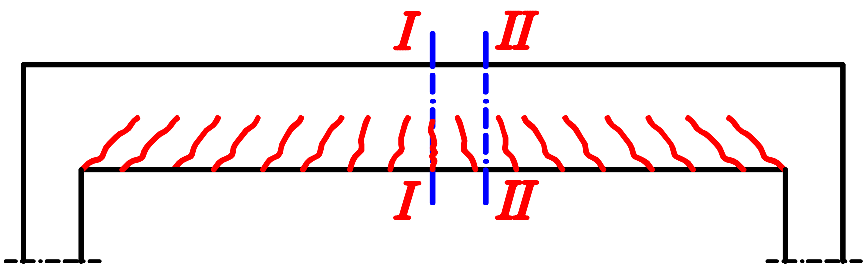
و ال $M_{act.}$ هو العزم المؤثر على الكمره نتيجه **Total working Loads**

IF $\boxed{M_{act} >>> M_{cr}}$

اذا كانت M_{act} اكبر بكثير من $M_{cr.}$

هذا يعنى ان عدد الشروخ كبير فتكون قيمه I_e أقرب لقيمه I_{nv}



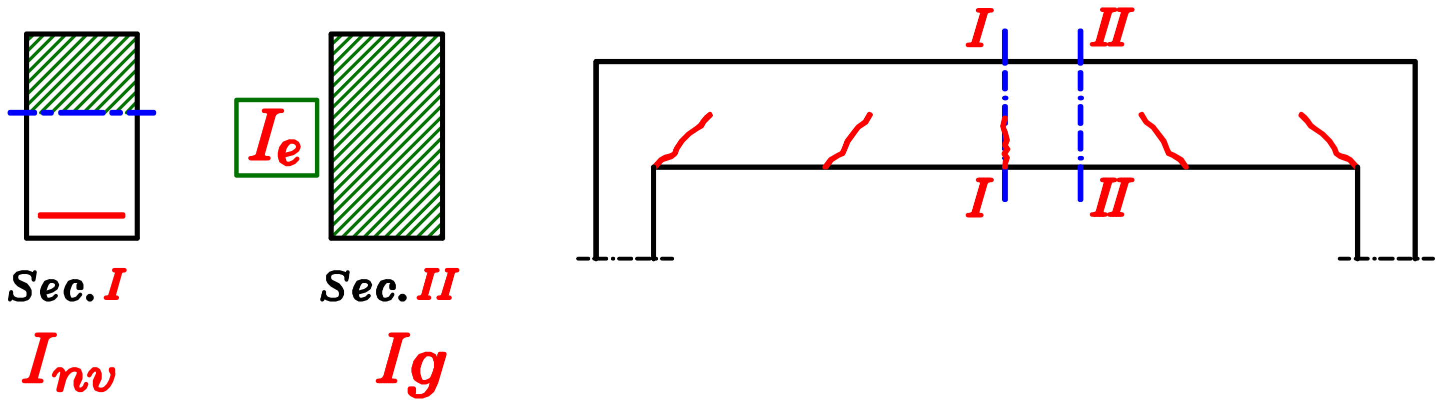


Sec. I
I_{nv}

Sec. II
I_g

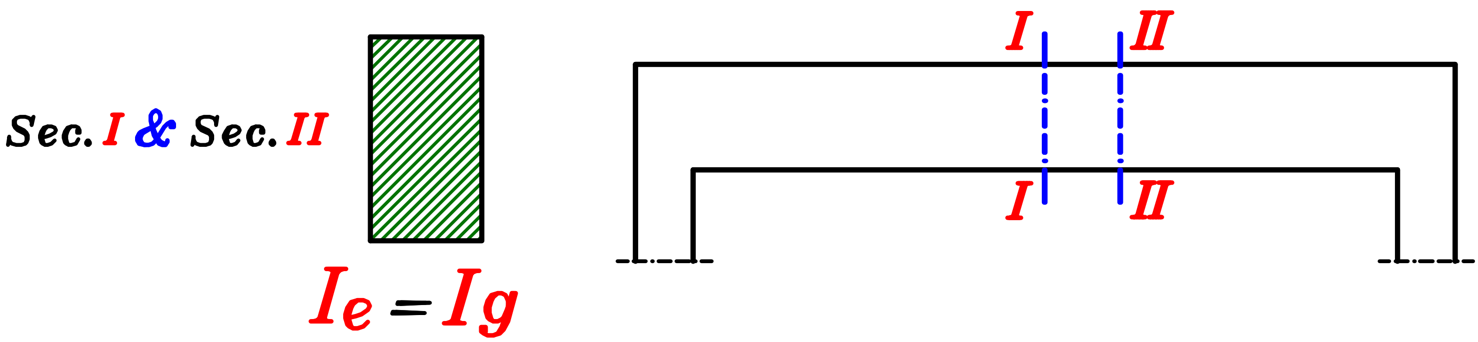
IF $\boxed{M_{act} > M_{cr}}$ اذا كانت M_{act} اكبر من $M_{cr.}$ لكن بقيمه قليله

هذا يعنى انه يوجد شروخ لكن عددها قليل اى ان قيمه I_e أقرب لقيمه I_g



اذا كانت M_{act} اقل من $M_{cr.}$

هذا يعنى انه لا يوجد شروخ بالكمره و تكون قيمه I_e تساوى I_g



اذا لحساب قيمه I_e يحسب من القانون التالى

$$I_e = Factor * I_g + \left[1 - Factor\right] I_{nv}$$

و هذا ال $Factor$ بالطبع يعتمد على كل من M_{act} & M_{cr}

$$\boxed{Factor = \left(\frac{M_{cr}}{M_{act}}\right)^3}$$

$$\boxed{I_e = \left(\frac{M_{cr}}{M_{act}}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_{act}}\right)^3\right] I_{nv}}$$

$$I_e = \left(\frac{M_{cr}}{M_{act}}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_{act}}\right)^3\right] I_{nv}$$

اذا لحساب قيمه I_e يجب قبلها ان نحسب كل من

1- $I_g = \checkmark$

2- $M_{cr} = F_{ctr} * \dfrac{I_g}{\bar{y}_{ten}} = \checkmark$

3- $M_{cr} = \checkmark$ due to total working load

IF $\boxed{M_{cr}}$

$M_{act.} \leqslant M_{cr}$

$$\boxed{I_e = I_g}$$

$M_{act.} > M_{cr}$

4- $I_{nv} = \checkmark$

$$I_e = \left(\frac{M_{cr}}{M_{act}}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_{act}}\right)^3\right] I_{nv}$$

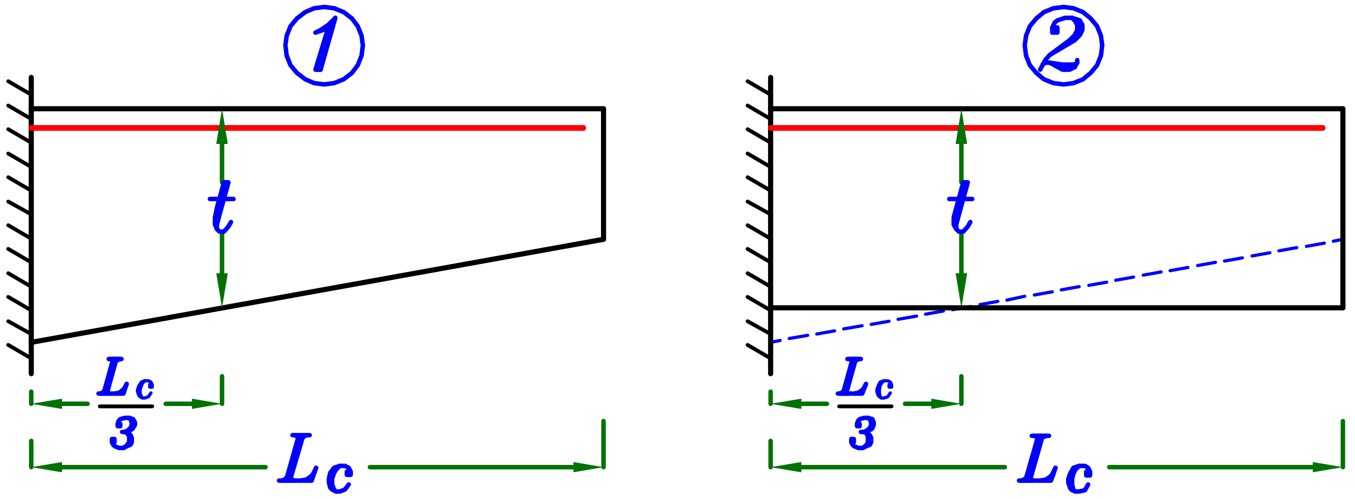
Special Cases.

For Cantilever with Variable depth.

وجد ان قيمه deflection للـ Variable depth Cantilever

هى نفس قيمه deflection لـ Constant depth Cantilever لكن بتخانه أقل

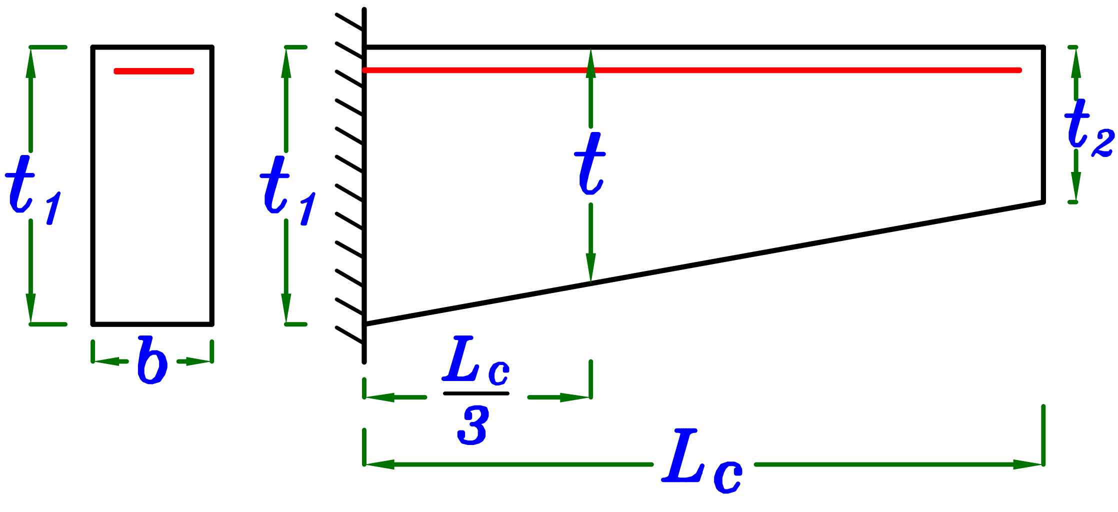
و وجد ان هذه التخانه مساويه للتخانه عند بعد $\frac{L_c}{3}$ من ال Fixation

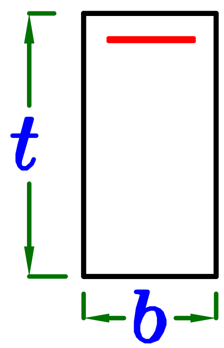


$$\Delta_{act\,1} = \Delta_{act\,2}$$

اذا لحساب deflection للـ Variable depth Cantilever

ممكن استخدام نفس القوانين السابقه لكن حساب I_g & I_{nv} لقطاع على بعد $\frac{L_c}{3}$ من ال Fixation





Take the properties of the section at $\frac{L_c}{3}$

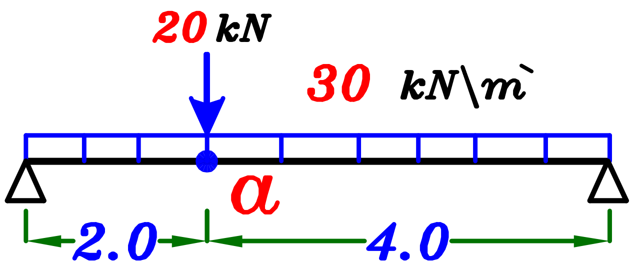
Actual Deflection Values. Δ_{act}

نحسب قيمه Δ_{act} عن طريق الـ **working loads**

و ممكن حساب قيمه الـ **deflection** بأى طريقه مثلا بطريقه **Conjugate beam**

Example.

Calculate Δ_{act} at point a



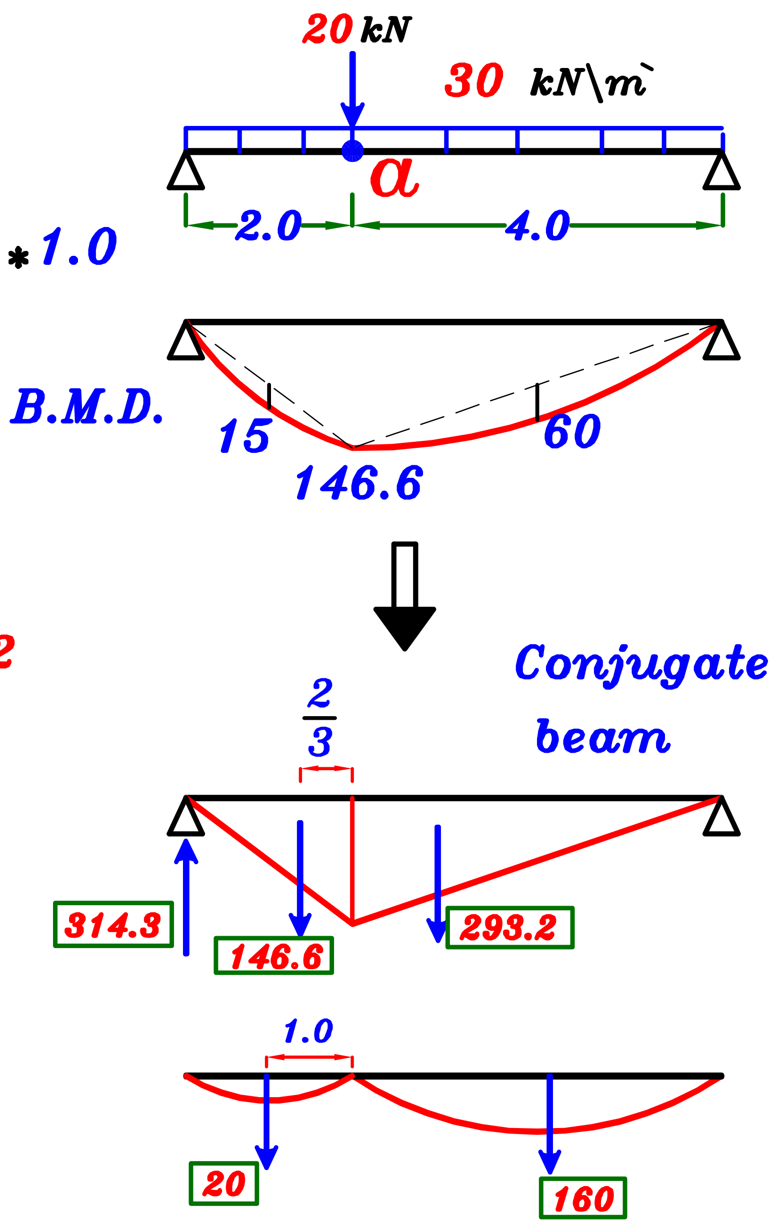
$$E_c\, I_e * \Delta_{act} =$$

$$= 314.3 * 2 - 146.6 * \frac{2}{3} - 20 * 1.0$$

$$= 510.86 \text{ kN.m.m.m}$$

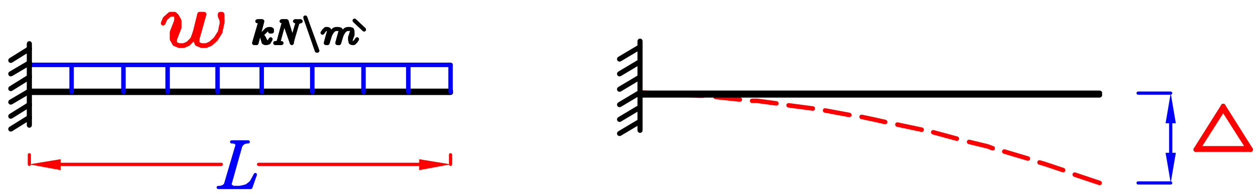
لتحويلها الى N.mm.mm.mm

$$\therefore \quad \Delta_{act} = \frac{510.86 * 10^{12}}{E_c\, I_e}$$



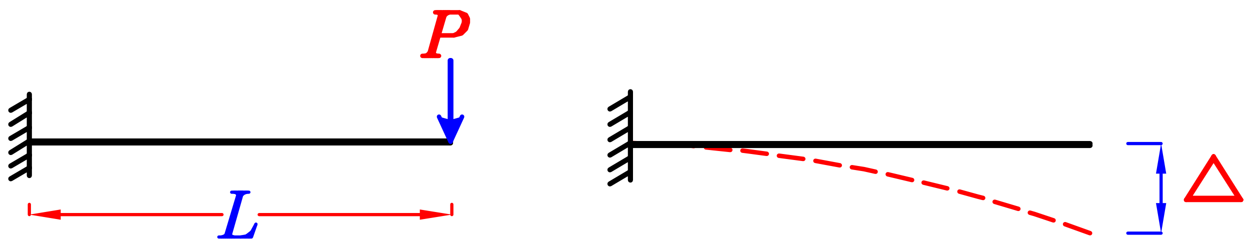
توجد عده حالات محفوظه لل **Deflection** ممكن استخدامها مباشره .

①



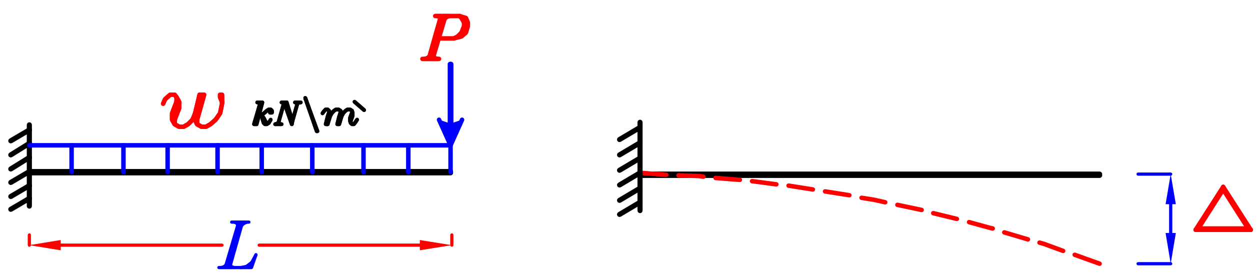
$$\triangle_{act} = \frac{1}{8} * \frac{w L^4}{E_c I_e}$$

②



$$\triangle_{act} = \frac{1}{3} * \frac{P L^3}{E_c I_e}$$

③

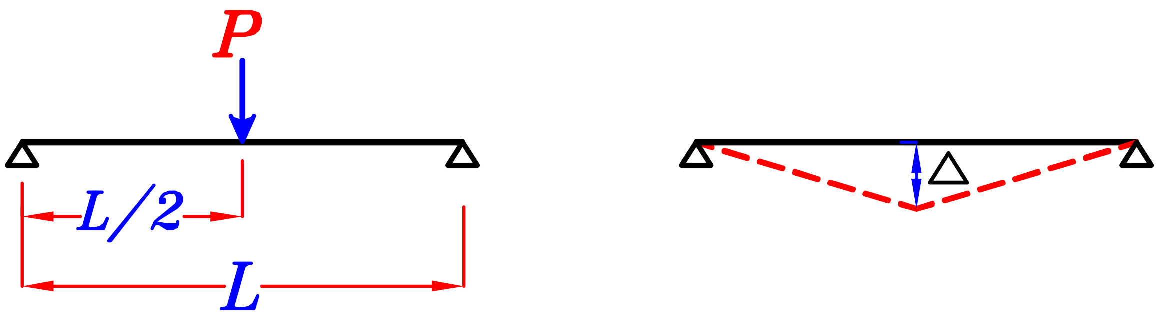


$$\triangle_{act} = \frac{1}{8} * \frac{w L^4}{E_c I_e} + \frac{1}{3} * \frac{P L^3}{E_c I_e}$$

④

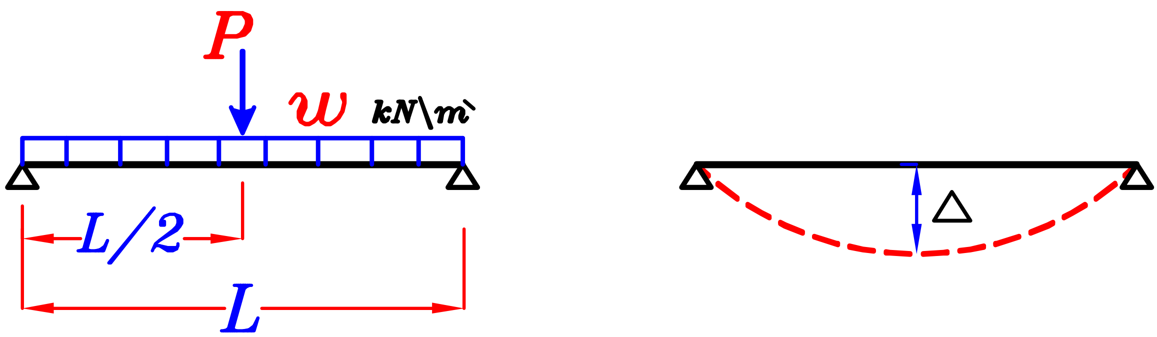
$$\boxed{\Delta_{act} = \frac{5}{384} * \frac{w\,L^4}{E_c\,I_e}}$$

⑤



$$\boxed{\Delta_{act} = \frac{1}{48} * \frac{P\,L^3}{E_c\,I_e}}$$

⑥

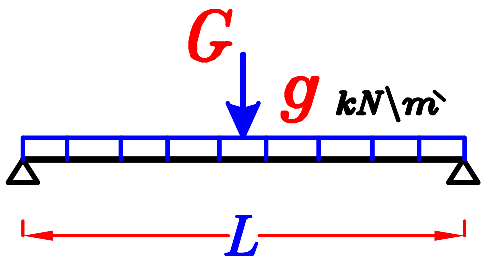


$$\boxed{\Delta_{act} = \frac{5}{384} * \frac{w\,L^4}{E_c\,I_e} + \frac{1}{48} * \frac{P\,L^3}{E_c\,I_e}}$$

Actual Deflection due to Dead Load.

نستخدم نفس القوانين السابقه لكن مع استخدام D.L. فقط

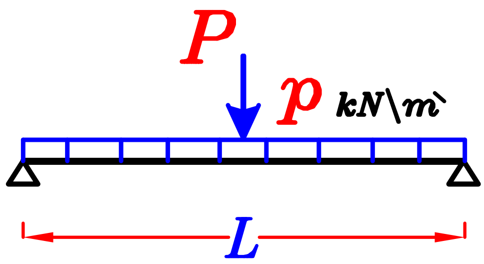
$$\Delta_{D.L.} = \frac{5}{384} * \frac{g\,L^4}{E_c\,I_e} + \frac{1}{48} * \frac{G\,L^3}{E_c\,I_e}$$



Actual Deflection due to Live Load.

نستخدم نفس القوانين السابقه لكن مع استخدام L.L. فقط

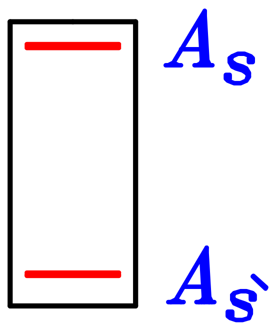
$$\Delta_{L.L.} = \frac{5}{384} * \frac{p\,L^4}{E_c\,I_e} + \frac{1}{48} * \frac{P\,L^3}{E_c\,I_e}$$



Actual Deflection due to Creep. الزحف

$$\Delta_{Creep} = \alpha\ \Delta_{D.L.}$$

$$\boxed{\alpha = 2.0 - 1.2\left(\frac{A_s^`}{A_s}\right) \geqslant 0.6}$$



$$\boxed{\text{Short Term Deflection.} = \Delta_{D.L.} + \Delta_{L.L.}}$$

$$\boxed{\text{Long Term Deflection.} = \Delta_{D.L.} + \Delta_{L.L.} + \Delta_{Creep}}$$

Actual Deflection due to Non structural elements.

(Deflection due to Partitions)

اذا كانت الكمره أو البلاطه تحمل عناصر غير انشائيه و كانت هذه العناصر كبيره التأثر بال *Deflection* مثل ال *curtain walls* أو الواجهات الزجاجيه يجب حساب قيمه *Deflection* يسمى $\triangle_p$

$$\boxed{\triangle_p = \triangle_{L.L.} + \alpha \triangle_{sus}}$$

Where: $\alpha = 2.0 - 1.2\left(\frac{A_s'}{A_s}\right) \geq 0.6$

$\triangle_{sus}$ هى قيمه ال *Deflection* الحاصل من ال *dead loads* مضافا عليه الاحمال الحيه الشبه ثابتة مثل الفواصل

$$\boxed{\triangle_{sus} = \triangle_{D.L.} + Finish\ Factor * \triangle_{L.L.}}$$

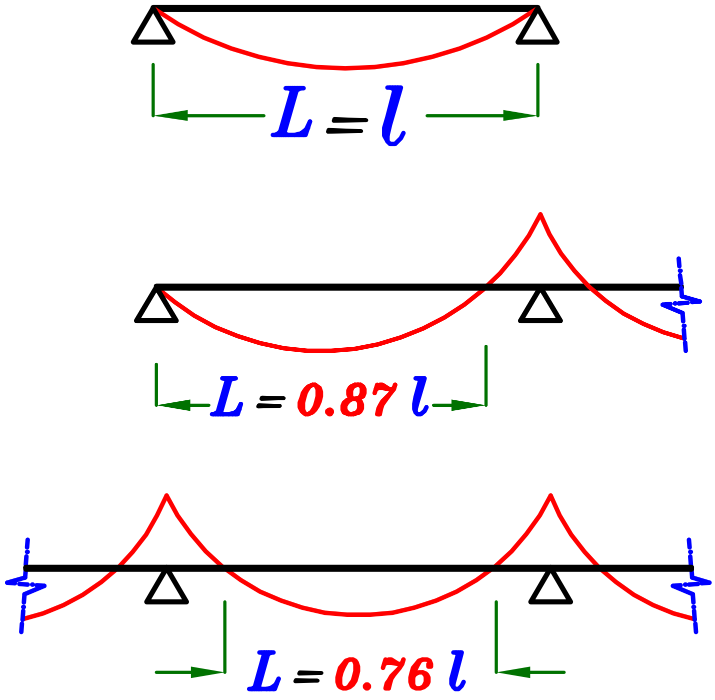
$$Finish\ Factor \simeq 0.15 \longrightarrow 0.30$$

ملحوظه .

لن يتم حساب قيمه $\triangle_p$ اذا لم يتم تحديد قيمه ال *Finish Factor*

Allowable Deflection Values. $\Delta_{all.}$

For Beams.



$$\boxed{\Delta_{all} = \frac{L}{250}}$$

Compared with

$$\boxed{\Delta_{D.L.} + \Delta_{L.L.} + \Delta_{Creep}}$$

$$\boxed{\Delta_{all} = \frac{L}{360}}$$

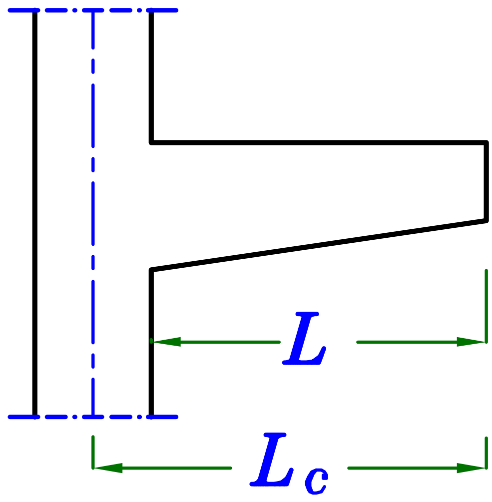
Compared with $\boxed{\Delta_{L.L.} \text{ Only}}$

$$\boxed{\Delta_{all} = \frac{L}{480}}$$

In case Finish Factor is given

Compared with $\boxed{\Delta_{p} = \Delta_{L.L.} + \alpha \, \Delta_{sus}}$

For Cantilever.



$$\boxed{\Delta_{all} = \frac{L}{450}}$$

Compared with

$$\boxed{\Delta_{D.L.} + \Delta_{L.L.} + \Delta_{Creep}}$$

$$\boxed{\Delta_{all} = \frac{L}{480}}$$

In case Finish Factor is given

Compared with

$$\boxed{\Delta_{L.L.} + \alpha\, \Delta_{sus}}$$

Steps of Check Deflection.

* get $E_c = 4400\sqrt{F_{cu}}$
* get $I_e = \left(\frac{M_{cr}}{M_{act}}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_{act}}\right)^3\right] I_{nv}$
* get $\Delta_{D.L.}$ & $\Delta_{L.L.}$
* get Short Term deflection. $= \Delta_{D.L.} + \Delta_{L.L.}$
* get $\alpha = 2.0 - 1.2\left(\frac{A_s'}{A_s}\right) \geqslant 0.6$
* get $\Delta_{Creep} = \alpha\,\Delta_{D.L.}$
* get Long Term deflection. $= \Delta_{D.L.} + \Delta_{L.L.} + \Delta_{Creep}$
* get $\Delta_{sus} = \Delta_{D.L.} +$ Finish Factor $* \Delta_{L.L.}$

  Only If the Finish Factor is given.

Compare Actual Deflections with Allowable Deflection.

– For Beams

$\Delta_{all} = \frac{L}{250}$ with $\Delta_{act} = \Delta_{D.L.} + \Delta_{L.L.} + \Delta_{Creep}$

$\Delta_{all} = \frac{L}{360}$ with $\Delta_{act} = \Delta_{L.L.}$

$\Delta_{all} = \frac{L}{480}$ with $\Delta_{act} = \Delta_p = \Delta_{L.L.} + \alpha\,\Delta_{sus}$

– For Cantlever

$\Delta_{all} = \frac{L}{450}$ with $\Delta_{act} = \Delta_{D.L.} + \Delta_{L.L.} + \Delta_{Creep}$

$\Delta_{all} = \frac{L}{480}$ with $\Delta_{act} = \Delta_p = \Delta_{L.L.} + \alpha\,\Delta_{sus}$

IF $\Delta_{act.} \leqslant \Delta_{all}$ Safe Deflection.

IF $\Delta_{act.} > \Delta_{all}$ UnSafe Deflection.

4-3-1 DEFORMATION AND DEFLECTION LIMIT STATES			
$\Delta_{D.L+L.L+creep}$	$<$ L/250	beams	4-60-a
	L' /450	cantilevers	4-60-b
$\Delta_{D.L+finishes+creep}$	$<$ L/350 or 20mm	slabs & beams	4-60-c
	L' /600	cantilevers	4-60-d
Modulus of elasticity of concrete	$E_c = 14000\sqrt{f_{cu}}$ kg/cm^2		4-61
Effective moment of inertia $I_e = (M_{cr}/M_a)^3 \, I_g + [1-(M_{cr}/M_a)^3] \, I_{cr}$			4-62
Cracking moment $M_{cr} = (f_{ctr} \, I_g) \, / \, y_t$			4-63
Tensile concrete strength	$f_{ctr} = 0.75 \, (f_{cu})^{2/3}$ kg/cm^2		4-64
$\Delta_{creep} = \alpha \, \Delta_{D.L}$ where $\alpha = 2 - 1.2 \, (A'_s/A_s) \geq 0.6$			4-65

فى العمل

اذا وجدنا ان $\Delta_{act} = \Delta_{D.L.} + \Delta_{L.L.} > \Delta_{all}$

اى ان الكمره **Unsafe Deflection**

ممكن ان نشترط فى التنفيذ ان يتم عمل تحديب للشده الخشب **Cambering**
عند المنطقه التى عندها اكبر **Deflection**

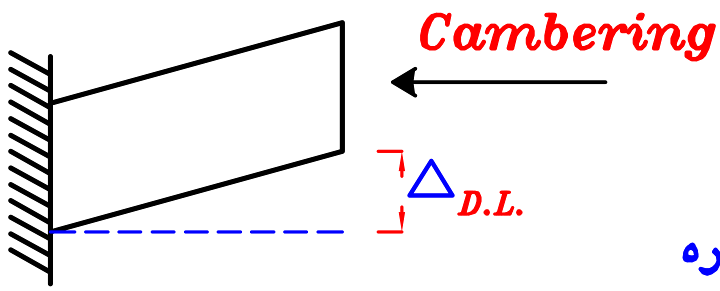
و ذلك برفع مستوى الشده الخشب فى هذه المنطقه بمقدار $\Delta_{D.L.}$

فتكون الكمره بعد الصب مائله لاعلى بمقدار $\Delta_{D.L.}$

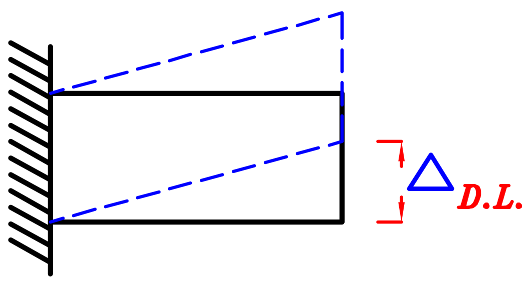
و عند فك الشده الخشب تكون الكمره محمله بـ **D.L.** فقط فتصبح الكمره افقيه

و عند وضع **L.L.** على الكمره سيحدث لها **Deflection** قيمته $\Delta_{L.L.}$ فقط.

فتصبح قيمه $\Delta_{act} = \Delta_{L.L.} < \Delta_{all}$ فتصبح الكمره **Safe Deflection**



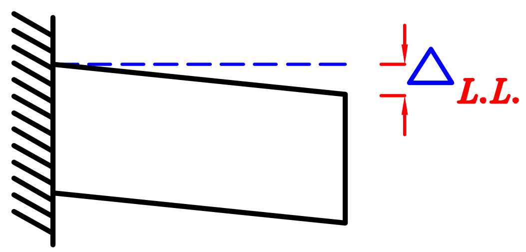
قبل فك الشده الخشب



بعد فك الشده الخشب مباشره

توجد فقط أحمال **D.L.**

$$\Delta_{act} = 0.0$$



بعد وضع أحمال الـ **L.L.**

$$\Delta_{act} = \Delta_{L.L.} < \Delta_{all}$$

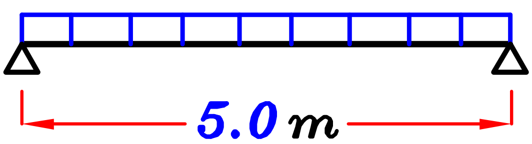
Safe Deflection.

Example.

working Loads

$g = 18.0\ kN\backslash m'$

$p = 30.0\ kN\backslash m'$



$F_{cu} = 25\ N\backslash mm^2$

st. 360/520 , Finish Factor = 0.20

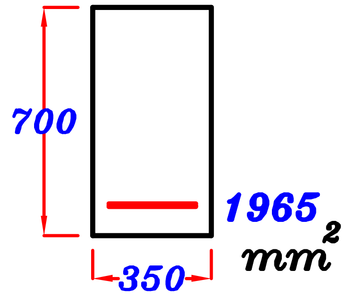
For the shown Beam

Calculate.

1 – the maximum immediate (Short Term) Deflection.

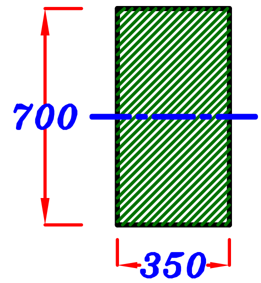
2 – Long Term deflection.

3 – Check Code Limits For deflection.



$$- E_c = 4400\sqrt{F_{cu}} = 4400\sqrt{25} = 22000\ N\backslash mm^2$$

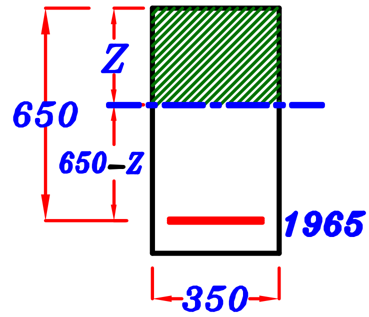
$$- I_g = \frac{b\,t^3}{12} = \frac{350 * 700^3}{12} = 10004166670\ mm^4$$



$$- \bar{y} = \frac{t}{2} = \frac{700}{2} = 350\ mm$$

$$- \because S_{nv.\ above\,(N.A.)} = S_{nv.\ under\,(N.A.)} \quad \therefore \frac{b\,Z^2}{2} = n\,A_s(d - Z)$$

$$\therefore \frac{350\,(Z)^2}{2} = 15\,(1965)\,(650 - Z) \longrightarrow Z = 257.2\ mm$$



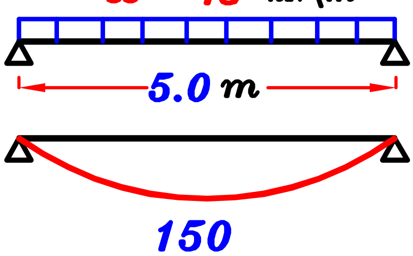
$$- I_{nv} = \frac{b\,Z^3}{3} + n\,A_s\,(d - Z)^2$$

$$= \frac{350\,(257.2)^3}{3} + 15\,(1965)\,(650 - 257.2)^2 = 6532748196\ mm^4$$

$$- F_{ctr} = 0.6\sqrt{F_{cu}} = 0.6\sqrt{250} = 3.0\ N\backslash mm^2$$

$$- M_{cr} = F_{ctr} * \frac{I_g}{\bar{y}_{ten}} = \frac{3.0 * 10004166670}{350} = 85750000\ N.mm = 85.75\ kN.m$$

$$- M_{act.} = (g + p)\,\frac{L^2}{8} = 48\,\frac{(5)^2}{8} = 150\ kN.m$$



$$\therefore M_{act} > M_{cr}$$

$$- I_e = \left(\frac{M_{cr}}{M_{act}}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_{act}}\right)^3\right] I_{nv}$$

$$I_e = \left(\frac{85.75}{150}\right)^3 (10004166670) + \left[1 - \left(\frac{85.75}{150}\right)^3\right] (6532748196)$$

$$I_e = 7181286422 \ mm^4$$

Actual Deflections.

$$- \triangle_{D.L.} = \frac{5}{384} * \frac{g \ L^4}{E_c \ I_e} = \frac{5}{384} * \frac{\left(18 * \frac{1000}{1000}\right)(5.0 * 1000)^4}{(22000)(7181286422)}$$

$$= 0.92 \ mm$$

$$- \triangle_{L.L.} = \frac{5}{384} * \frac{p \ L^4}{E_c \ I_e} = \frac{5}{384} * \frac{\left(30 * \frac{1000}{1000}\right)(5.0 * 1000)^4}{(22000)(7181286422)}$$

$$= 1.54 \ mm$$

$$- \triangle_{Creep} \qquad \alpha = 2.0 - 1.2\left(\frac{A_s`}{A_s}\right) = 2.0 - 1.2\left(\frac{0.0}{1965}\right) = 2.0$$

$$\triangle_{Creep} = \alpha \ \triangle_{D.L.} = 2.0 \ (0.92) = 1.84 \ mm$$

$$- \triangle_{sus} = \triangle_{D.L.} + \text{Finish Factor} * \triangle_{L.L.}$$

$$= 0.92 + 0.20 * 1.54 = 1.228 \ mm$$

$$- \triangle p = \triangle_{L.L.} + \alpha \ \triangle_{sus}$$

$$= 1.54 + 2.0 * 1.228 = 4.0 \ mm$$

- **Short Term Deflection.**

$$= \Delta_{D.L.} + \Delta_{L.L.} = 0.92 + 1.54 = 2.46 \ mm$$

- **Long Term Deflection.**

$$= \Delta_{D.L.} + \Delta_{L.L.} + \Delta_{Creep}$$

$$= 0.92 + 1.54 + 1.84 = 4.30 \ mm$$

Compare Actual Deflections with Allowable Deflection.

$$\Delta_{all} = \frac{L}{250} = \frac{5000}{250} = 20 \ mm$$

$$\Delta_{act} = \Delta_{D.L.} + \Delta_{L.L.} + \Delta_{Creep} = 4.30 \ mm$$

$\because \Delta_{act} \leqslant \Delta_{all} \longrightarrow$ **Safe Deflection.**

$$\Delta_{all} = \frac{L}{360} = \frac{5000}{360} = 13.90 \ mm$$

$$\Delta_{act} = \Delta_{L.L.} = 1.54 \ mm$$

$\because \Delta_{act} \leqslant \Delta_{all} \longrightarrow$ **Safe Deflection.**

$$\Delta_{all} = \frac{L}{480} = \frac{5000}{480} = 10.417 \ mm$$

$$\Delta_{act} = \Delta_{p} = \Delta_{L.L.} + \alpha \, \Delta_{sus} = 4.0 \ mm$$

$\because \Delta_{act} \leqslant \Delta_{all} \longrightarrow$ **Safe Deflection.**

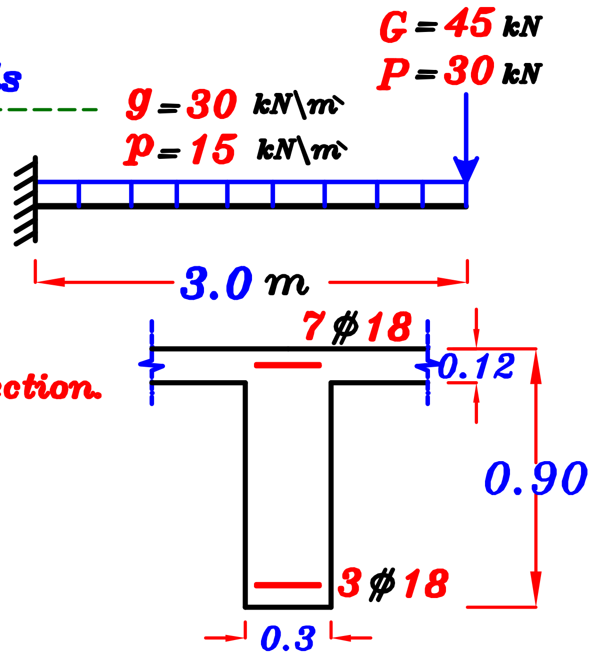
$\because$ **All the checks are safe**

$\therefore$ $\boxed{\textbf{The beam is Safe Deflection}}$

Example.

$F_{cu} = 25 \ N\backslash mm^2$ st. 360/520

U.L. Loads



For the shown cantilever

Calculate:

1 – the maximum immediate (Short Term) Deflection.

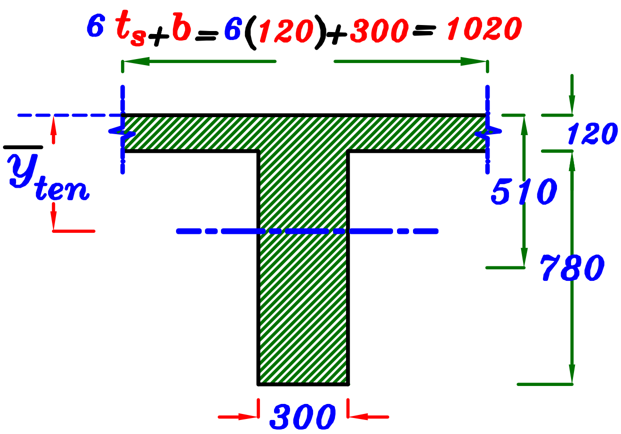
2 – Long Term deflection.

3 – Check Code Limits For deflection.

Factored Loads

Solution.

– $E_c = 4400\sqrt{F_{cu}} = 4400\sqrt{25} = 22000 \ N\backslash mm^2$



$$A = 120 * 1020 + 300 * 780 = 356400 \ mm^2$$

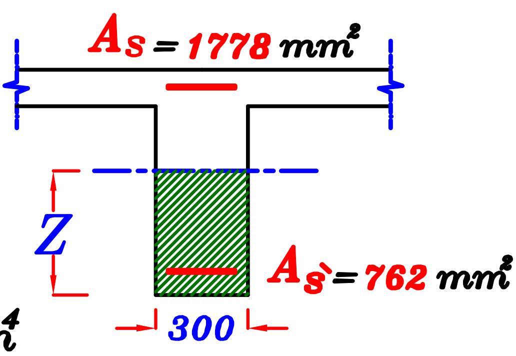
$$\overline{y} = \frac{120 * 1020 * 60 + 300 * 780 * 510}{356400} = 355.45 \ mm$$

$$I_g = \frac{300 * 780^3}{12} + 300 * 780 \ (154.55)^2 + \frac{1020 * 120^3}{12} + 1020 * 120 \ (295.45)^2$$

$$= 28284316370 \ mm^4$$

$\because S_{nv_{above\ (N.A.)}} = S_{nv_{under\ (N.A.)}}$ $\therefore \frac{b\,Z^2}{2} + (n-1)\,A_s'\,(Z-d') = n\,A_s\,(d-Z)$

$$\frac{300\,(Z)^2}{2} + (15-1)(762)\,(Z-50) = 15\,(1778)\,(850-Z) \longrightarrow Z = 288.0 \ mm$$



$$- I_{nv} = \frac{b\,Z^3}{3} + (n-1)A_s'(Z-d')^2 + n\,A_s\,(d-Z)^2$$

$$= \frac{300\,(288.0)^3}{3} + (15-1)\,(762)\,(288.0-50)^2$$

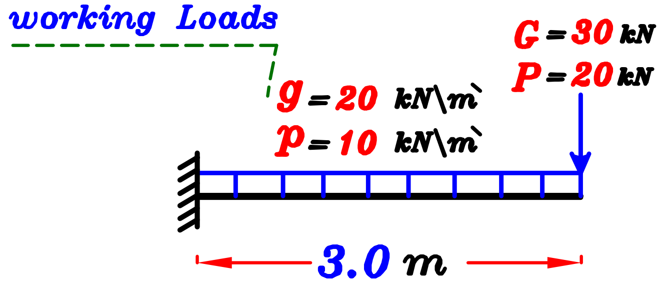
$$+ 15\,(1778)\,(850-288.0)^2 = 11416624870 \ mm^4$$

$$- \ F_{ctr} = 0.6\sqrt{F_{cu}} = 0.6\sqrt{250} = 3.0 \ N\backslash mm^2$$

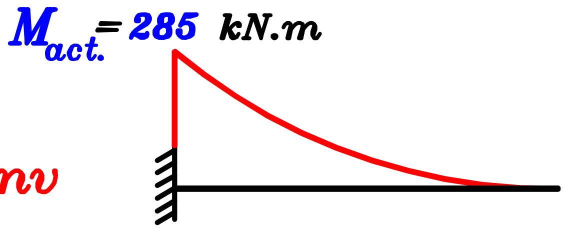
$$- \ M_{cr} = F_{ctr} * \frac{I_g}{y_{ten}} = \frac{3.0 * 28284316370}{355.45} = 238719789 \ N.mm = 238.7 \ kN.m$$

$$- \ M_{act.} = (G+P)\,L + (g+p)\frac{L^2}{2}$$

$$= 50\,(3) + 30\,\frac{(3)^2}{2} = 285 \ kN.m$$



$$\therefore \quad M_{act} > M_{cr}$$



$$- \ I_e = \left(\frac{M_{cr}}{M_{act}}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_{act}}\right)^3\right] I_{nv}$$

$$I_e = \left(\frac{238.7}{285}\right)^3 (28284316370) + \left[1 - \left(\frac{238.7}{285}\right)^3\right] (11416624870)$$

$$I_e = 21326731480 \ mm^4$$

$$- \ \Delta_{D.L.} = \frac{1}{8} * \frac{g\,L^4}{E_c\,I_e} + \frac{1}{3} * \frac{G\,L^3}{E_c\,I_e}$$

$$\Delta_{D.L.} = \frac{1}{8} * \frac{\left(20 * \frac{1000}{1000}\right)(3.0 * 1000)^4}{(22000)(21326731480)} + \frac{1}{3} * \frac{(30 * 10^3)(3.0 * 1000)^3}{(22000)(21326731480)} = 1.007 \ mm$$

$$- \ \Delta_{L.L.} = \frac{1}{8} * \frac{p\,L^4}{E_c\,I_e} + \frac{1}{3} * \frac{P\,L^3}{E_c\,I_e}$$

$$\Delta_{L.L.} = \frac{1}{8} * \frac{\left(10 * \frac{1000}{1000}\right)(3.0 * 1000)^4}{(22000)(21326731480)} + \frac{1}{3} * \frac{(20 * 10^3)(3.0 * 1000)^3}{(22000)(21326731480)} = 0.599 \ mm$$

$$- \ \Delta_{Creep}$$

$$\alpha = 2.0 - 1.2\left(\frac{A_s'}{A_s}\right) = 2.0 - 1.2\left(\frac{762}{1778}\right) = 1.485$$

$$\Delta_{Creep} = \alpha \ \Delta_{D.L.} = 1.485\ (1.007) = 1.495 \ mm$$

- **Short Term Deflection.**

$$= \Delta_{D.L.} + \Delta_{L.L.} = 1.007 + 0.599 = 1.606 \text{ mm}$$

- **Long Term Deflection.**

$$= \Delta_{D.L.} + \Delta_{L.L.} + \Delta_{Creep} = 1.007 + 0.599 + 1.495 = 3.10 \text{ mm}$$

Compare Actual Deflections with Allowable Deflection.

$$\Delta_{all} = \frac{L}{450} = \frac{3000}{450} = 6.60 \text{ mm}$$

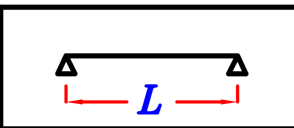
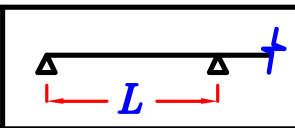
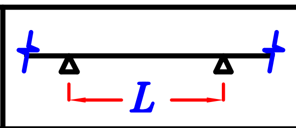
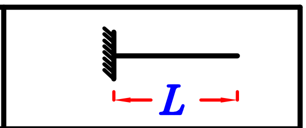
$$\Delta_{act} = \Delta_{D.L.} + \Delta_{L.L.} + \Delta_{Creep} = 3.10 \text{ mm}$$

$$\because \Delta_{act} \leqslant \Delta_{all} \longrightarrow \boxed{\text{The beam is Safe Deflection}}$$

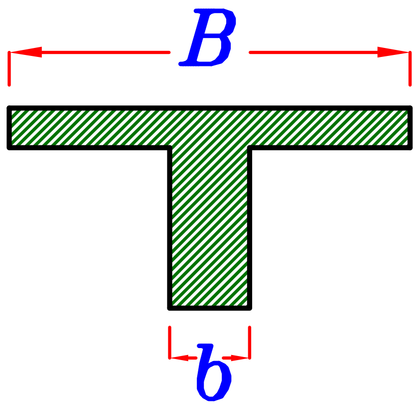
Note.

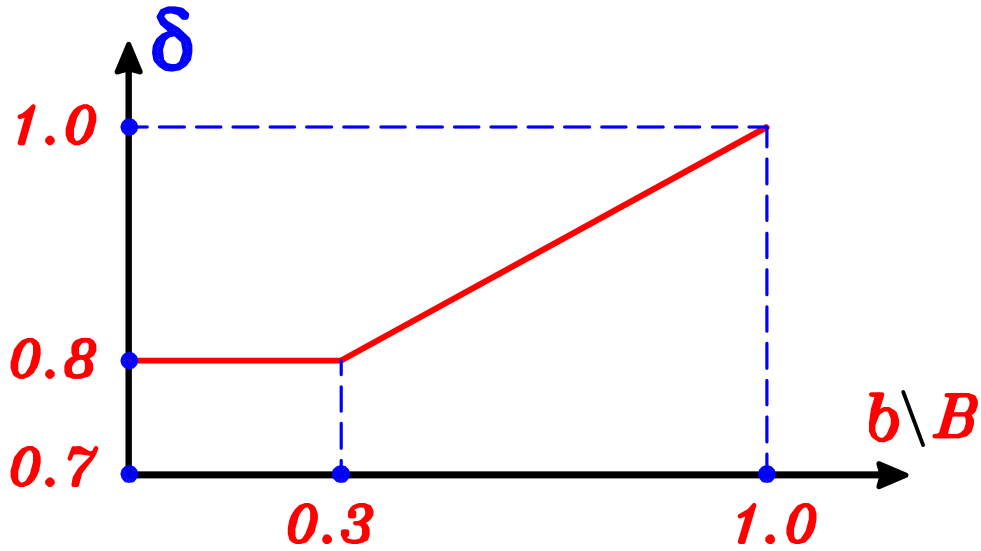
ممكن اهمال عمل *check deflection* اذا كانت نسبه بحر الكمره

الى عمقها لا يزيد عن القيم التاليه $(L \backslash t)$

				
st. 360\520 400\600	16	18	21	5
st. 240\350	16 * 1.25	18 * 1.25	21 * 1.25	5 * 1.25

اذا كان القطاع *T-section* نضرب هذه القيم فى δ *Factor*





لن تنفع هذه القيم و بالتالى يجب عمل *Check Deflection* فى الحالات التاليه :

١ - أن يزيد بحر الكمره عن ١٠ م

٢ - أن تكون الكمره معرضه لاحمال كبيره أو أحمال مركزه .

٣ - أن يكون عمق الكمره متغير *variable depth*

Cracks Control.

تنقسم المنشأت الخرسانية الى ٤ أقسام حسب تعرضها للرطوبه و عوامل تأكل الحديد .

و لمنع تأكل الحديد يجب أن لا يزيد عرض الشرخ عن قيمه $W_{K max}$

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Category	Crack Width $W_{K max}$ (mm)	Degree of Exposure درجة التعرض للرطوبه	نوع المنشأ
one	0.30 mm	منشأت محميه Protected structures.	المنشأت العاديه الغير معرضة للرطوبه
Two	0.20 mm	Unprotected منشأت غير محميه open air structures.	الكبارى و المنشأت المجاوره للمجارى المائيه
Three	0.15 mm	معرضة للرطوبه Severally Exposed	خزانات المياه
Four	0.10 mm	معرضة بشده للرطوبه very Severally Exposed	مواسير الصرف الخرسانيه و أحواض معالجه المياه

The Factors Affecting the Crack Width. W_K

العوامل المؤثره على شروخ الخرسانه

1 − Steel stress. (F_s) $W_K \propto F_s$

2 − Steel strength. (F_y) $W_K \propto \frac{1}{F_y}$

3 − Bond between steel & concrete. --------- $W_K \propto \frac{1}{Bond}$

4 − Steel bar diameter. (ϕ) $W_K \propto \phi$

5 − Steel type (Smooth or deformed)

6 − Concrete strength (F_{cu}) ----- $W_K \propto \frac{1}{F_{cu}}$

7 − Concrete cover. $W_K \propto \frac{1}{Cover}$

8 − $\mu = \frac{A_s}{A_c}$ $W_K \propto \frac{1}{\mu}$

9 − $\alpha = \frac{A_s'}{A_s}$ $W_K \propto \alpha$

Category	Degree of exposure to environmental effects
One	Structures with *protected* tension side such as a) All protected internal members of ordinary buildings. b) Permanently submerged members in water (without harmful materials) or members permanently dry. c) Well isolated roofs against moisture and rains.
Two	Structures with *unprotected* tension side, such as: a) Structures in open air, e.g. bridges and roofs without good insulation. b) Structures of category one built nearby seashores. c) Structures subjected to humidity such as open halls, sheds and garages.
Three	Structures with *severely exposed* tension side, such as: a) Members with high exposure to humidity. b) Members exposed to repeated saturation with moisture. c) Water tanks. d) Structures subjected to vapour, gases or weak chemical attacks.
Four	Structures with tension side *very severely* exposed to corrosive influences of strong chemical attacks which cause rusting of steel a) Structures subjected to conditions resulting in rust of steel such as gases and vapour including chemicals. b) Other tanks, sewerage, Structures subjected to seawater.

كلما زادت نسبه الحديد فى القطاع $\mu = \frac{A_s}{A_c}$ كلما قل عرض الشرخ W_K

فيتم وضع معامل تخفيض لـ F_y للعمل على زياده كميه الحديد

ليقل الشرخ و يسمى هذا المعامل β_{Cr}

ECCS Design Aids Page 8−4

To Use β_{Cr} Get the Category No. and Get ϕ we use.

Then Get β_{Cr} From ECCS Page 8−4

① Case of M only.

$$A_s = \frac{1}{\beta_{Cr}} \left(\frac{M_{U.L.}}{J\, F_y\, d} \right)$$

② Case of M , N

$$A_s = \frac{1}{\beta_{Cr}} \left(\frac{M_s}{J\, F_y\, d} - \frac{N_{U.L.}}{(F_y \backslash \gamma_s)} \right)$$

③ Case of T only.

$$A_s = \frac{1}{\beta_{Cr}} \left(\frac{T_{U.L.}}{(F_y \backslash \gamma_s)} \right)$$

f_s (N/mm^2) W.S.D	Reduction factor L.S.D β_{cr}		Category one	Category two	Categories three & four
	36/52	40/60	Largest Bar diameter (ϕ_{max}) in mm		
220	1.00	0.92	18	12	8
200	0.93	0.83	22	16	10
180	0.85	0.75	25	20	12
160	0.75	0.67	32	22	18
140	0.65	0.58	--	25	22
120	0.56	0.50	--	--	28

Example.

$F_{cu} = 25$ N\mm^2 st. 360/520 $b = 250$ mm

$M_{U.L.} = 400$ kN.m Cat. II

Req: Get d , A_s

Solution.

Take $d = C_1 \sqrt{\dfrac{M_{U.L.}}{F_{cu}\, b}}$ $C_1 = 3.5$, $J = 0.78$

$$\therefore d = 3.5 \sqrt{\frac{400 * 10^6}{25 * 250}} = 885.4 \text{ mm}$$

Take $\boxed{d = 900 \text{ mm}}$, $\boxed{t = 950 \text{ mm}}$

$$\therefore A_s = \frac{1}{\beta_{Cr}} \left[\frac{M_{U.L.}}{J\, F_y\, d} \right] = \frac{1}{\beta_{Cr}} \left[\frac{400 * 10^6}{0.78 * 360 * 885.4} \right]$$

$$\therefore A_s = \frac{1}{\beta_{Cr}} [1609] \text{ mm}^2$$

$\therefore$ From ECCS Design Aids Page 8–4 Cat. II

IF we use $\phi 12 \longrightarrow \beta_{Cr} = 1.0 \longrightarrow A_s = \frac{1}{1.0}[1609] = 1609 \text{ mm}^2$ 15ϕ12

IF we use $\phi 16 \longrightarrow \beta_{Cr} = 0.93 \longrightarrow A_s = \frac{1}{0.93}[1609] = 1730 \text{ mm}^2$ 9ϕ16

IF we use $\phi 18 \longrightarrow \beta_{Cr} = 0.85 \longrightarrow A_s = \frac{1}{0.85}[1609] = 1893 \text{ mm}^2$ 8ϕ18

IF we use $\phi 20 \longrightarrow \beta_{Cr} = 0.85 \longrightarrow A_s = \frac{1}{0.85}[1609] = 1893 \text{ mm}^2$ 6ϕ20

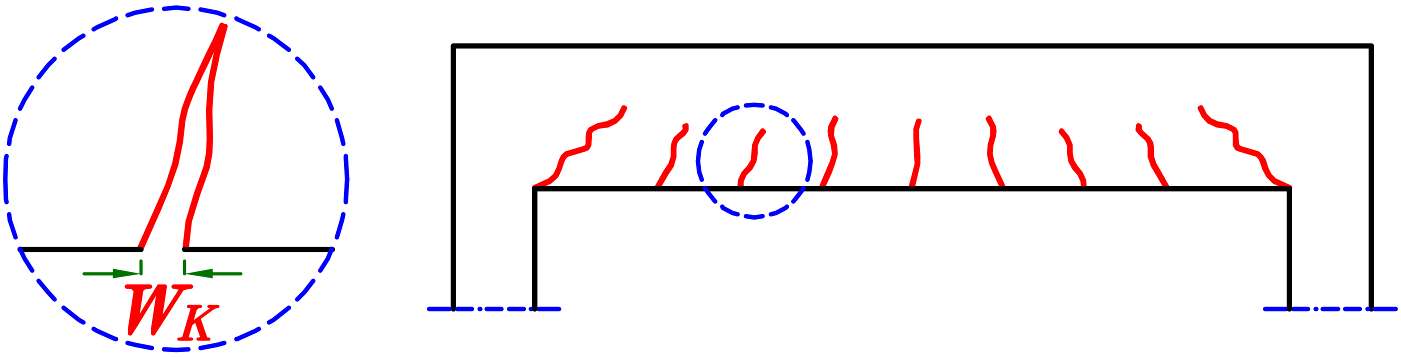
Check Crack width.

عند تصميم العناصر الخرسانيه المسلحه يجب استيفاء العلاقه التاليه :

$$W_K \leqslant W_{K\,max}$$

ECCS Design Aids Pages 8−2 & 8−3

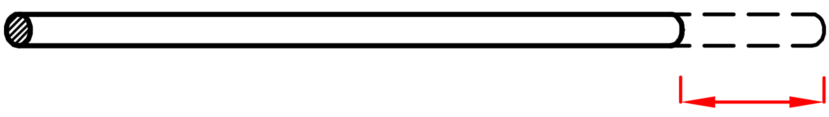
حيث W_K هو عرض الشرخ جهه الشد بال مم .



$W_{K\,max}$ هو أكبر عرض شرخ مسموح به بال مم .

Category	One	Two	Three	Four
$W_{K\,max}$ (mm)	0.30	0.20	0.15	0.10

ε_{sm} هى استطاله الحديد فى الكمره



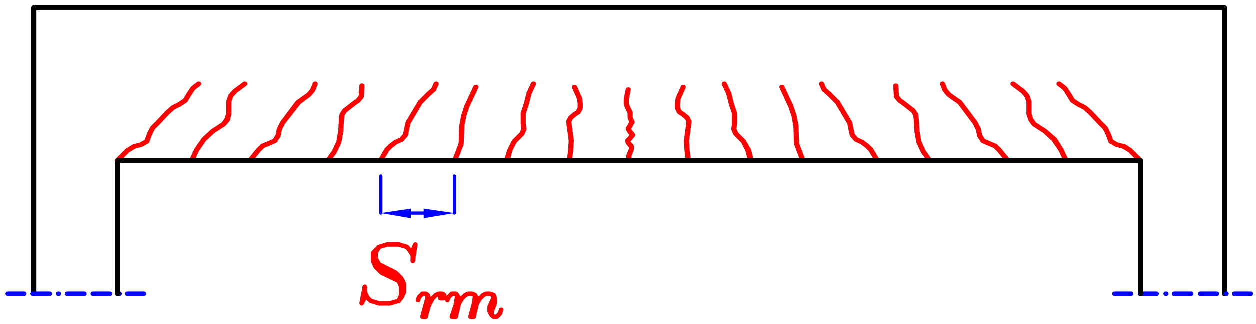
كلما زادت استطاله الحديد كلما زاد عرض الشرخ .

$$\varepsilon_{sm} \propto W_K$$

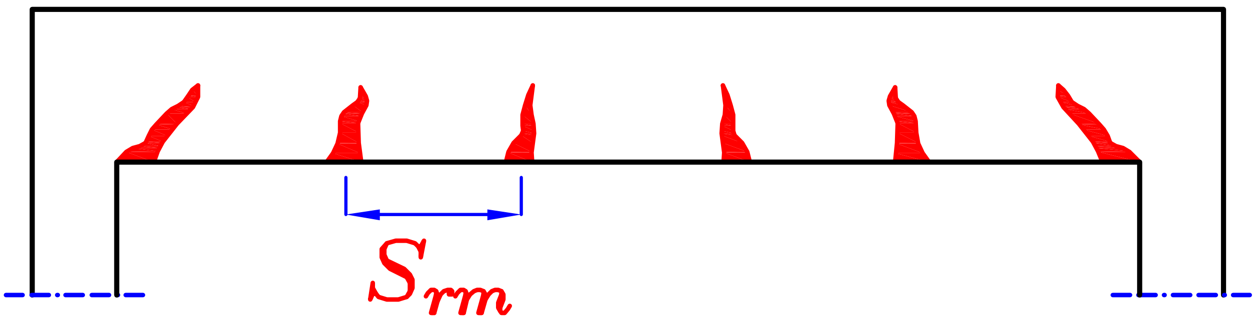
S_{rm} هى المسافه بين كل شرخ و الذى يليه بال مم

بما ان مجموع عرض الشروخ ثابت = استطاله الحديد

اذا كلما زاد عدد الشروخ كلما قلت المسافه بينهم و كلما قل عرض الشرخ



اذا كلما قل عدد الشروخ كلما زادت المسافه بينهم و كلما زاد عرض الشرخ



$$\boxed{S_{rm} \propto W_K}$$

To Calculate crack width W_K

$$\boxed{W_K = \beta * S_{rm} * \varepsilon_{sm}} \quad mm$$

حيث β هى معامل يربط العلاقه بين متوسط عرض الشرخ و القيمه التصميميه لعرض الشرخ .

Take $\boxed{\beta = 1.70}$ فى حاله الشروخ الناتجه عن الاحمال

حيث S_{rm} هى المسافه بين الشروخ بال مم .

$$\boxed{S_{rm} = \left[50 + 0.25\ K_1\ K_2\ \frac{\phi}{\rho_r}\right]} \quad mm$$

حيث ε_{sm} هى الزياده المتوسطه للانفعال فى الصلب بالنسبه للخرسانه حول الصلب .

$$\boxed{\varepsilon_{sm} = \frac{F_s}{E_s}\left[1 - \beta_1\ \beta_2 \left(\frac{F_{sr}}{F_s}\right)^2\right]}$$

To Calculate S_{rm}

$$\boxed{S_{rm} = \left[50 + 0.25\ K_1\ K_2\ \frac{\phi}{\rho_r} \right]} \quad mm$$

حيث K_1 هى معامل يعكس تأثير التماسك بين الخرسانه و الحديد على المسافه بين الشروخ .

Take $K_1 = 0.80$ For Deformed Bars

$K_1 = 1.60$ For Smooth Bars

حيث K_2 هى معامل يعكس تأثير شكل توزيع الانفعالات فى القطاع على المسافه بين الشروخ .

Take $K_2 = 0.50$ For Pure Bending.

$K_2 = 1.0$ For Pure axial Tension.

حيث ϕ هو قطر السيخ المستخدم فى القطاع بال مم

$$\boxed{\rho_r = \frac{A_s}{A_{cef}}}$$

حيث ρ_r هى نسبه تسليح الشد الفعال .

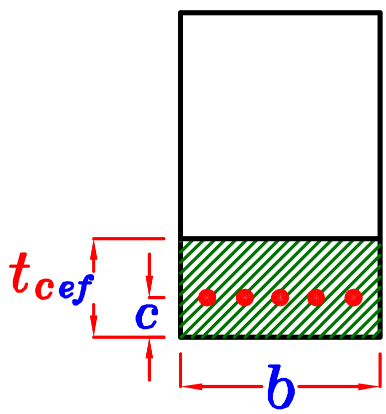
A_s هى مساحه الحديد جهه الشد .

A_{cef} هى مساحه قطاع الخرسانه الفعال فى الشد .

$$\boxed{A_{cef} = b * t_{cef}}$$

$$\boxed{t_{cef} = 2.5\ (c)}$$

c is the cover



To Calculate ε_{sm}

$$\boxed{\varepsilon_{sm} = \frac{F_s}{E_s}\left[1 - \beta_1\,\beta_2\left(\frac{F_{sr}}{F_s}\right)^2\right]}$$

حيث β_1 هى معامل يعكس تأثير التماسك بين الخرسانه و الحديد
على الزياده المتوسطه للانفعال فى الصلب بالنسبه للخرسانه .

Take $\beta_1 = 0.80$ For Deformed Bars

$\beta_1 = 0.50$ For Smooth Bars

حيث β_2 هى معامل يأخذ تأثير فتره التحميل على الزياده المتوسطه
للانفعال فى الصلب بالنسبه للخرسانه .

Take $\beta_2 = 1.0$ Short Term loading.

$\beta_2 = 0.50$ Long Term loading.

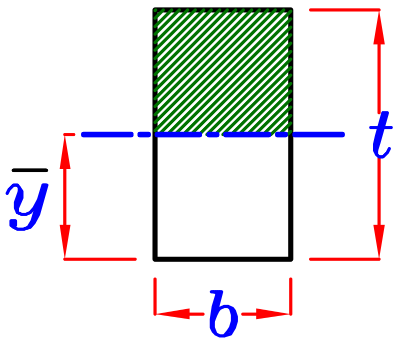
حيث E_s هى معاير المرونه لحديد الصلب

$\boxed{E_s = 2.0 * 10^5}$ N/mm^2

Properties of the section.

* $\bar{y} = \frac{t}{2}$

* $I_g = \frac{b\,t^3}{12}$



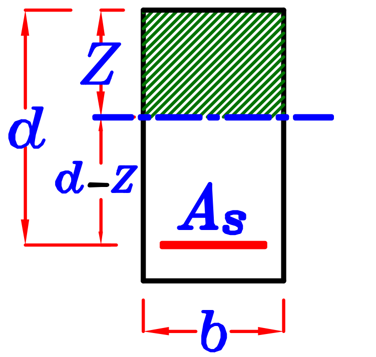
* $F_{ctr} = 0.6\sqrt{F_{cu}}$ $N\backslash mm^2$

* $M_{cr} = F_{ctr} * \frac{I_g}{\bar{y}}$

* $n = 15$ Modular Ratio

* Z From $\frac{b\,Z^2}{2} - n\,A_s\,(d - Z) = 0.0$

* $I_{nv} = \frac{b\,Z^3}{3} + n\,A_s\,(d - Z)^2$



* M_{act} is the actual moment due to working loads.

حيث F_s الاجهاد فى صلب التسليح جهه الشد فى القطاع بعد التشرخ و المحسوب على أساس قطاع مشرخ تحت تأثير أحمال التشغيل .

$$\boxed{F_s = n \, \frac{M_{act}\,(d - Z)}{I_{nv}}}$$

حيث F_{sr} الاجهاد فى صلب التسليح ناحيه الشد فى القطاع و المحسوب على أساس قطاع مشرخ عند حدوث أول شرخ تحت تأثير الاحمال المسببه لاول حاله تشرخ .

$$\boxed{F_{sr} = n \, \frac{M_{cr}\,(d - Z)}{I_{nv}}}$$

Then get $W_K = \beta * S_{rm} * \varepsilon_{sm}$

Compare this value with $W_{K\,max}$

ECCS Design Aids Pages 8-2

Category	*One*	*Two*	*Three*	*Four*
$W_{K\,max}$ (mm)	0.30	0.20	0.15	0.10

* *IF* $W_K \leqslant W_{K\,max} \longrightarrow$ *Safe Crack width.*
* *IF* $W_K > W_{K\,max} \longrightarrow$ *Unsafe Crack width.*

8.2 Satisfaction of Cracking Limit State

When designing reinforced concrete structures, one should fulfil the following relation:

$$w_k = \beta . s_{rm} . \varepsilon_{sm}$$

$$s_{rm} = \left(50 + 0.25 K_1 K_2 \frac{\phi}{\rho_r} \right)$$

$$\varepsilon = \frac{f_s}{E_s} \left(1 - \beta_1 \beta_2 \left(\frac{f_{sr}}{f_s} \right)^2 \right)$$

with the values of W_k less than or equal to the values w_{kmax} given in Table (8-2):

Table (8-2)Values of w_{kmax}

Category	One	Two	Three	Four
$w_{k(max)}$	0.3	0.2	0.15	0.1

In case of members subjected to imposed deformation, the values of k_1 shall be modified to kk_1 where the value of k is taken as follows:

a) k=0.80 for the case in which the tensile stresses are induced due to restraining the deformation. For rectangular cross section, the value of k is taken as follows:

k=0.8 for rectangular section having thickness ≤ 300 mm.

k=0.50 for rectangular sections having thickness ≤ 800 mm.

b) k=1.0 for cases in which the tensile stresses are induced due to restraint of extrinsic deformation.

k_2 = Coefficient that reflects the strain distribution over the cross section subjection. It shall be taken equal to 0.5 for sections subjected to pure bending and 1.0 for sections subjected to pure axial tension. For section subjected to combined bending and axial tension, k_2 shall be calculated from:

$$k_2 = \frac{\varepsilon_1 + \varepsilon_2}{2\,\varepsilon_2}$$

Where ε_1 and ε_2 are the maximum and minimum strain values to which the section is subjected, and shall be calculated based on the analysis of a cracked section.

ρ_r = effective tension reinforcement ratio.

$$\rho_r = \frac{A_s}{A_{cef}}$$

where

A_s = area of longitudinal tension steel within the effective tension area

A_{cef} = area of effective concrete section in tension.

= width of the section * t_{cef}

t_{cef} can be calculated according to Fig. (4.22) of ECCS 203-2001.

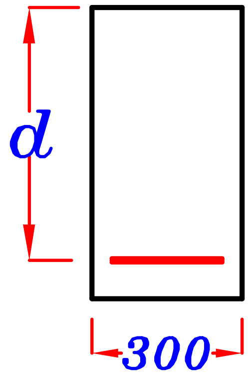
f_s = stress in longitudinal steel at the tension zone, calculated based on the analysis of cracked section under permanent loads.

f_{sr} = stress in longitudinal steel at the tension zone, calculated based on the analysis of cracked section due to loads causing first cracking.

Example.

$F_{cu} = 25\ N\backslash mm^2$, st. 360/520

$M_{U.L.} = 300\ kN.m$ Category II



Required:

1 – Design the section to safty crack limits.

2 – Check crack width. W_K

Solution.

Take $d = C_1 \sqrt{\dfrac{M_{U.L.}}{F_{cu}\, b}}$ $C_1 = 3.5$, $J = 0.78$

$$\therefore\ d = 3.5 \sqrt{\frac{300 * 10^6}{25 * 300}} = 700\ mm$$

Take $\boxed{d = 700\ mm}$, $\boxed{t = 750\ mm}$

$$\therefore A_s = \frac{1}{\beta_{Cr}} \left[\frac{M_{U.L.}}{J\, F_y\, d} \right] = \frac{1}{\beta_{Cr}} \left[\frac{300 * 10^6}{0.78 * 360 * 700} \right]$$

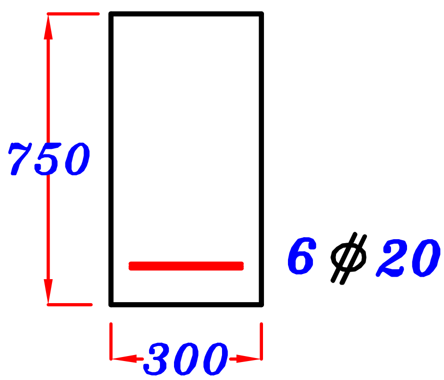
$$\therefore A_s = \frac{1}{\beta_{Cr}} [1526]\ mm^2$$

$\therefore$ From ECCS Design Aids Page 8–4 Cat. II

using $\phi 20 \longrightarrow \beta_{Cr} = 0.85$

$$A_s = \frac{1}{0.85} [1526] = 1795\ mm^2$$

6 ϕ 20



2- Check crack width. W_K

* $W_{Kmax} = 0.20$ mm

* $W_K = \beta * S_{rm} * \varepsilon_{sm}$

- $\boxed{\beta = 1.70}$ For cracks induced due to loading.

* $S_{rm} = \left[50 + 0.25\ K_1\ K_2\ \dfrac{\phi}{\rho_r}\right]$

- $K_1 = 0.80$ For Deformed Bars
- $K_2 = 0.50$ For Pure Bending.
- $\phi = 20$ mm
- $\rho_r = \dfrac{A_s}{A_{cef}}$ $\qquad A_s = 6\phi 20 = 1884\ mm^2$

$t_{cef} = 2.5\ (c) = 2.5\ (50) = 125$ mm

$A_{cef} = b * t_{cef} = 300\ (125) = 37500\ mm^2$

$$\rho_r = \frac{A_s}{A_{cef}} = \frac{1884}{37500} = 0.0502$$

$$S_{rm} = \left[50 + 0.25\ K_1\ K_2\ \frac{\phi}{\rho_r}\right]$$

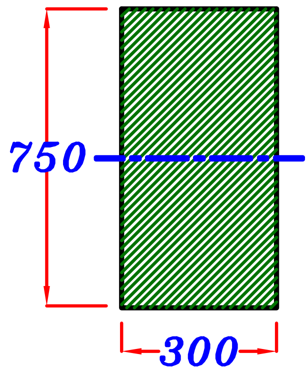
$$S_{rm} = \left[50 + 0.25\ (0.80)\ (0.50) \left(\frac{20}{0.0502}\right)\right] = 89.84\ mm$$

$$\boxed{S_{rm} = 89.84\ mm}$$

$$* \quad \varepsilon_{sm} = \frac{F_s}{E_s}\left[1 - \beta_1 \beta_2 \left(\frac{F_{sr}}{F_s}\right)^2\right]$$

- $\beta_1 = 0.80$ For Deformed Bars.
- $\beta_2 = 0.50$ Long Term loading.
- $E_s = 2.0 * 10^5 \quad N/mm^2$

Properties of the section.

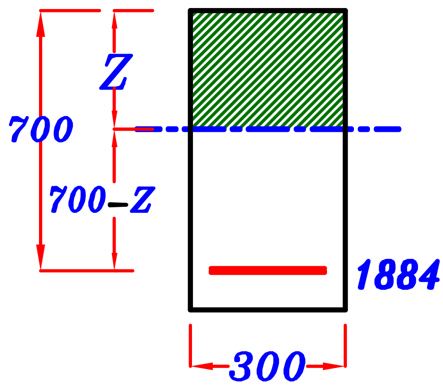


- $\bar{y} = \frac{t}{2} = \frac{750}{2} = 375 \ mm$
- $I_g = \frac{b\,t^3}{12} = \frac{300 * 750^3}{12} = 10546875000 \ mm^4$
- $F_{ctr} = 0.6\sqrt{F_{cu}} = 0.6\sqrt{250} = 3.0 \quad N\backslash mm^2$
- $M_{cr} = F_{ctr} * \frac{I_g}{\bar{y}_{ten}} = \frac{3.0 * 10546875000}{375}$

$$= 84375000 \ N.mm = 84.375 \ kN.m$$

$$\boxed{n = 15}$$

- $M_{act} = \frac{M_{U.L.}}{1.50} = \frac{300}{1.50} = 200 \quad kN.m$



- Z From $\frac{b\,Z^2}{2} - n\,A_s\,(d - Z) = 0.0$

$$\therefore \frac{300\,(Z)^2}{2} - 15\,(1884)\,(700 - Z) = 0.0$$

$$\therefore Z = 280.97 \quad mm$$

- $I_{nv} = \frac{b\,Z^3}{3} + n\,A_s\,(d - Z)^2$

$$I_{nv} = \frac{300\,(280.97)^3}{3} + 15\,(1884)\,(700 - 280.97)^2 = 7180157869 \ mm^4$$

$$* \quad F_s = n \frac{M_{act}\,(d - Z)}{I_{nv}}$$

$$F_s = 15 * \frac{200 * 10^{6}\,(700 - 280.97)}{7180157869} = 175.08 \quad N\backslash mm^2$$

$$* \quad F_{sr} = n \frac{M_{cr}\,(d - Z)}{I_{nv}}$$

$$F_{sr} = 15 * \frac{84.375 * 10^{6}\,(700 - 280.97)}{7180157869} = 73.86 \quad N\backslash mm^2$$

$$* \quad \varepsilon_{sm} = \frac{F_s}{E_s} \left[1 - \beta_1\,\beta_2 \left(\frac{F_{sr}}{F_s}\right)^2\right]$$

$$\varepsilon_{sm} = \frac{175.08}{2.0 * 10^{5}} \left[1 - (0.80)\,(0.50)\left(\frac{73.86}{175.08}\right)^2\right] = 8.13 * 10^{-4}$$

$$\boxed{\varepsilon_{sm} = 8.13 * 10^{-4}}$$

$$W_K = \beta * S_{rm} * \varepsilon_{sm} = 1.7 * 89.84 * 8.13 * 10^{-4}$$

$$W_K = 0.124 \ mm < W_{Kmax} = 0.20 \ mm$$

$$\therefore \quad \boxed{\text{Safe Crack width}}$$